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Λ_b **Results from CDF**

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Λ_b Results from CDF

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Abstract

The CDF experiment has recorded 110 pb^{-1} of $p\bar{p}$ collisions at $\sqrt{s} = 1.8 \text{ TeV}$ during the 1993-1995 data taking period. Using this dataset, searches for exclusive and semileptonic Λ_b decays were performed. The Λ_b mass was measured to be $M_{\Lambda_b} = 5623 \pm 5(\text{stat.}) \pm 4(\text{syst.}) \text{ MeV}/c^2$, using a sample of exclusively reconstructed Λ_b candidate events in the $\Lambda_b \rightarrow \Lambda J/\psi$ channel. The Λ_b lifetime was measured to be $\tau_{\Lambda_b} = 1.32 \pm 0.08(\text{stat.}) \pm 0.05(\text{syst.}) \text{ ps}$, using a sample of 197 ± 25 partially reconstructed semileptonic $\Lambda_b \rightarrow \ell^- \Lambda_c^+ X$ decays, with Λ_c^+ reconstructed from its decay to the $pK^-\pi^+$ final state. Using the same decay channels, the product branching ratios were measured to be $f(b \rightarrow \Lambda_b) \cdot B(\Lambda_b \rightarrow \Lambda J/\psi) = 4.2 \pm 1.8(\text{stat.}) \pm 0.7(\text{syst.}) \times 10^{-5}$ and $f(b \rightarrow \Lambda_b) \cdot B(\Lambda_b \rightarrow \ell^- \Lambda_c^+ \bar{\nu}) \cdot B(\Lambda_c^+ \rightarrow pK^-\pi^+) = 9.3 \pm 2.5(\text{stat.}) \pm_{-4.0}^{+4.6}(\text{syst.}) \times 10^{-4}$, where $f(b \rightarrow \Lambda_b)$ is the fraction of b quarks forming b baryons, and ℓ is either an electron or a muon.

1 Introduction

The Λ_b baryon with constituent quark content of (udb) is expected to be the lightest baryon containing a b quark. Searches for signals of exclusive decays of the Λ_b beauty baryon have been performed by several experiments at hadron colliders and at LEP. A compilation of existing Λ_b results is presented in Table 1. The SFM collaboration at the ISR collider reported signals for the exclusive Λ_b decays into $pD^0\pi^-$ and $\Lambda_c^+\pi^-\pi^+\pi^-$ decay channels, with mass measurements of respectively $5640_{-200}^{+100}\text{MeV}/c^2$ and $5650_{-200}^{+150}\text{MeV}/c^2$ [1]. The UA1 experiment reported an excess of events in the exclusive decay channel $\Lambda_b \rightarrow \Lambda J/\psi$ at the $S\bar{p}pS$ collider [2]. Measurements of the Λ_b mass of $5640 \pm 50 \pm 30 \text{ MeV}/c^2$ and branching ratio of $1.8 \pm 1.0\%$, assuming a production fraction $f(b \rightarrow \Lambda_b)$ of 10%, were published. Searches for Λ_b events in this decay channel performed at LEP have been unsuccessful so far, and resulted in measurements of an upper limit at 90% Confidence Level (CL) on the product branching ratio $f(b \rightarrow \Lambda_b) \cdot B(\Lambda_b \rightarrow \Lambda J/\psi) < 3.4 \times 10^{-4}$ from OPAL [3] and $< 7 \times 10^{-4}$ from DELPHI [6]. A similar analysis performed by the CDF collaboration at the Tevatron using the 1988-89 data sample of 4 pb^{-1} resulted in an upper limit measurement of $< 5 \times 10^{-4}$ at 90 % CL [9].

Table 1: Summary of results on the Λ_b mass measurements, the production branching fractions, and its lifetime.

Exp.	Λ_b Decay Channel	#evts	Mass [MeV/c^2]	$f_b \cdot Br$ or (90% CL)	Lifetime [ps]
UA1 [2]	$\Lambda J/\psi$	16 ± 5	$5640 \pm 50 \pm 30$	$0.18 \pm 0.10\%$	
SFM [1]	$pD^0\pi^-$	52 ± 20	5640_{-210}^{+100}		
	$\Lambda_c^+\pi^-\pi^+\pi^-$	90 ± 21	5650_{-200}^{+150}		
CDF [9]	$\Lambda J/\psi$	2		$\leq 5 \times 10^{-4}$	
ALEPH [10]	$\Lambda_c^+\pi^-$	4	$5621 \pm 17 \pm 15$		
DELPHI [6]	$\Lambda_c^+\pi^-$	3			
	$\Lambda_c^+a_1^-$	1	$5668 \pm 16 \pm 8$		
DELPHI [6]	$\Lambda J/\psi$	0		$\leq 7 \times 10^{-4}$	
OPAL [3]	$\Lambda J/\psi$	0		$\leq 3.4 \times 10^{-4}$	
OPAL [5, 4]	$\Lambda_c^+\ell X$	69 ± 13		$0.8 \pm 0.3\%$	$1.14 \pm 0.22 \pm 0.07$
ALEPH [11, 12]	$\Lambda_c^+\ell X$	107		$1.5 \pm 0.4\%$	$1.24 \pm 0.15 \pm 0.05$
DELPHI [8, 7]	$\Lambda_c^+\ell X$	125		$1.2 \pm 0.4\%$	$1.19 \pm 0.21 \pm 0.08$

Other fully reconstructed exclusive decay channels of Λ_b were explored at LEP, leading to Λ_b mass measurements. Based on the analysis of three million hadronic Z decays, the DELPHI collaboration, using $\Lambda_b \rightarrow \Lambda_c^+\pi^-$ and $\Lambda_b \rightarrow \Lambda_c^+a_1^-$ decay channels with $\Lambda_c^+ \rightarrow pK^-\pi^+$, measured the Λ_b mass to be $5668 \pm 16(stat.) \pm 8(syst.) \text{ MeV}/c^2$ [6]. The ALEPH experiment, using four million hadronic Z decays and the fully reconstructed decay channel $\Lambda_b \rightarrow \Lambda_c^+\pi^-$, with ($\Lambda_c^+ \rightarrow pK^-\pi^+$, $p\bar{K}^0$ or $\Lambda^0\pi^+\pi^+\pi^-$), measured the Λ_b mass to be $5614 \pm 21(stat.) \pm 4(syst.) \text{ MeV}/c^2$ [10]. An accurate measurement of the Λ_b mass provides precision tests of theoretical mass predictions based on b hadron decay models and will be important for future studies of

the beauty baryon spectroscopy.

Precision measurements of heavy quark lifetimes from the observed weak decays of b hadrons and a measurement of the semileptonic branching fraction are important experimental components in the determination of the CKM mixing parameter V_{cb} . The b-quark decay process, and thus the heavy quark lifetime, may be affected by the presence of the light quarks in the hadron. This effect is expected to be smaller in the b hadron decays than in the c hadron decays, since the bottom quark is heavier than the charm quark. Based on the heavy quark mass expansion calculations in the framework of QCD, lifetimes of the b hadrons are expected to be equal to within 10%, with the largest variation expected for the b baryons. Verification of this prediction was made possible through an analysis of partially reconstructed semileptonic decays of b baryons. Experiments at the LEP collider provided measurements of the b baryon lifetime, based on the analyses of the charge correlations of $lepton - \Lambda^0$ or $lepton - \Lambda_c$ as an indication of the presence of a semileptonic b baryon decay. The existing b baryon lifetime results based on partially reconstructed semileptonic decays and the corresponding product branching fractions are summarized in Table 1.

In this presentation measurements of the Λ_b mass and its product branching fraction using the fully reconstructed decay channel $\Lambda_b \rightarrow \Lambda J/\psi$ are described. Using the semileptonic decay $\Lambda_b \rightarrow \ell \Lambda_c \nu$, the Λ_b lifetime and the product branching fraction $f(b \rightarrow \Lambda_b) \cdot B(\Lambda_b \rightarrow \ell \Lambda_c \nu X)$ were measured. Results presented in this report were based on a sample of 110 pb^{-1} of integrated luminosity collected by the CDF experiment during the 1993-1995 running of the Tevatron.

2 Λ_b Reconstruction

The Λ_b was reconstructed using the exclusive decays $\Lambda_b \rightarrow \Lambda J/\psi$ and $\Lambda_b \rightarrow \ell^- \Lambda_c^+ \bar{\nu}$. The selection procedures were applied to ensure high efficiency and effective reduction of either combinatoric background or backgrounds originating from other decays, when a candidate particle is assigned a wrong mass. The ionization energy loss information from the Central Tracking Chamber was used for particle identification. The measured energy loss value was compared with the expected energy loss calculated under the assumption that a candidate track is π , p or K , and was required to fall within two standard deviations of the expected energy loss.

The Λ_b mass was measured using the decay mode $\Lambda_b \rightarrow \Lambda J/\psi$, where the J/ψ was reconstructed through the decay $J/\psi \rightarrow \mu^\pm \mu^\mp$, and the oppositely charged muons were required to have an invariant mass in the range 2.8 - 3.4 GeV/c². Both muons were required to have the transverse momentum, p_t , greater than 2 GeV/c. The Λ decays were reconstructed through the decay channel $\Lambda \rightarrow p\pi$, where the highest momentum candidate track was assigned the proton mass. In addition, a subsample of events with two muon tracks reconstructed in the Silicon Vertex Detector, (SVX), was used for a precision dimuon vertex measurement. A kinematically similar decay chain $B^0 \rightarrow J/\psi K_s^0$, with $J/\psi \rightarrow \mu^\pm \mu^\mp$ and $K_s^0 \rightarrow \pi^+ \pi^-$ was used as a control sample.

The Λ was required to have a transverse flight distance greater than 1.0 cm and a transverse momentum greater than 1.5 GeV/c. A fit which simultaneously constrained the J/ψ mass

to the world average value [14] and the Λ momentum to point to the dimuon vertex was performed in order to reconstruct the Λ_b candidates. All Λ_b candidates were required to have transverse momentum greater than 6 GeV/c and pseudorapidity $|\eta|$ less than 1.0. For candidates reconstructed with SVX information, a proper lifetime cut of 100 μm was imposed; otherwise, a cut of $c\tau$ greater than 0 μm was used. Analogous selection cuts were applied to the control sample.

In the decay mode $\Lambda_b \rightarrow \ell^- \Lambda_c^+ \bar{\nu}$, the Λ_c^+ was fully reconstructed through the decay channel $\Lambda_c^+ \rightarrow p K^- \pi^+$. The Λ_c^+ produced in association with a right sign lepton serves as a signature of Λ_b production. The inclusive lepton trigger was fully efficient for electrons and muons with transverse momentum greater than 8 GeV/c. In the $\Lambda_c^+ \rightarrow p K^- \pi^+$ decay, the proton, kaon and pion candidate tracks were required to have transverse momenta greater than 1.5, 0.7 and 0.6 GeV/c respectively, and to be contained in $\eta - \phi$ cone of $\sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} \leq 0.8$ around the lepton direction. The ionization energy loss information was used for the proton candidate track to eliminate backgrounds from decays such as $D \rightarrow \pi K \pi$ and $D_s \rightarrow K K \pi$. The invariant mass, calculated using a vertex constrained fit, was required to be within the range 2260 - 2308 MeV/c². To ensure precise vertex reconstruction, three tracks were required to include SVX information. The Λ_c^+ candidate was combined with a negatively charge lepton. The $\ell^- \Lambda_c^+$ combination was required to have invariant mass between 3.5 and 5.6 GeV/c² and p_t greater than 8 GeV/c. Background $\ell^- \Lambda_c^+$ candidates produced from sources other than $\Lambda_b \rightarrow \ell^- \Lambda_c^+ \bar{\nu}$ have softer momenta and smaller invariant mass. Combinatorial backgrounds are expected to contribute equally to right sign ($\ell^- \Lambda_c^+$) and wrong sign ($\ell^+ \Lambda_c^+$) combinations.

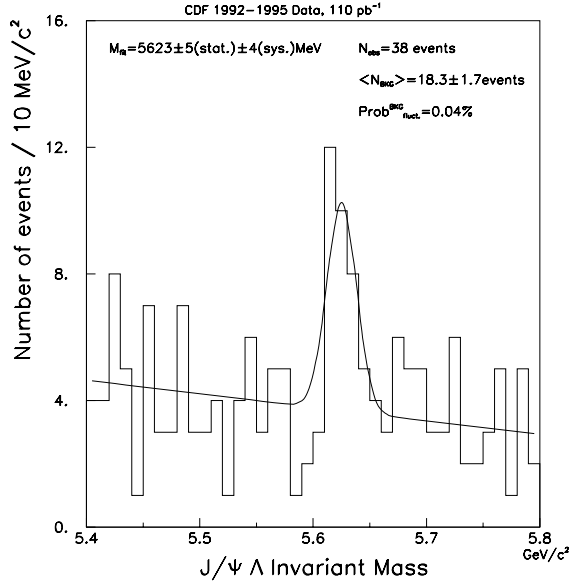


Figure 1: Invariant mass distribution of $\Lambda J/\psi$ with imposed fit results.

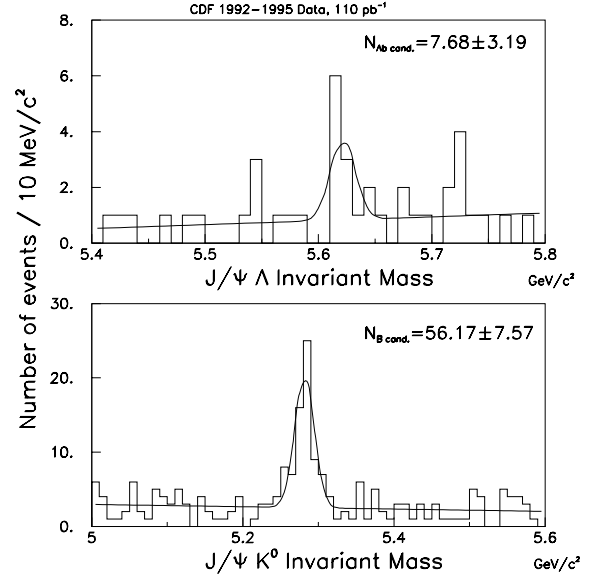


Figure 2: Invariant mass of $\Lambda J/\psi$ (top) and $J/\psi K_s^0$ (bottom) with imposed fit results.

3 Measurement of the Λ_b Mass

The invariant mass distribution of $\Lambda - J/\psi$ candidate events is shown in Figure 1. In the five bins between 5.60 and 5.65 GeV/c², 38 candidates are found. The expected mass resolution was determined from a control sample, using the decay $B_d^0 \rightarrow J/\psi K_s^0$. From a linear fit to the invariant mass distribution, the estimated number of background events in the same region was found to be 18.3 ± 1.7 events. The probability that the background fluctuates to the observed number of events in the five consecutive bins was calculated to be 0.04%, corresponding to a signal significance exceeding 3σ . The excess depends slightly on the definition of the signal search window and the background determination method. The enhancement of events in the $\Lambda - J/\psi$ mass distribution is interpreted as a Λ_b signal. An unbinned likelihood fit of a Gaussian and a linear function to the $\Lambda - J/\psi$ mass distribution resulted in a Λ_b mass of $M_{\Lambda_b^0} = 5.623 \pm 0.005(\text{stat.})$ GeV/c². Systematic errors on the Λ_b mass measurement are very similar to the uncertainties calculated in the B_s mass measurement [13]. The total systematic error in this measurement was found to be ± 0.004 GeV/c².

The reconstruction technique was studied on control samples of events such as $B_d^0 \rightarrow J/\psi K_s^0$. Since systematic effects impact the mass measurements of B_d^0 and Λ_b^0 similarly, they cancel out in the measurement of their mass difference, which was found to be $M_{\Lambda_b^0} - M_{B_d^0} = 342 \pm 6$ MeV/c².

4 Measurement of the $B(\Lambda_b \rightarrow \Lambda J/\psi)$

In the measurement of the branching fraction of the exclusive decay mode $B(\Lambda_b \rightarrow \Lambda J/\psi)$, the sample purity was improved by requiring that the dimuon pair be reconstructed in the SVX and that the p_t of the Λ decay products be greater than 400 MeV/c. The invariant mass distributions for the Λ_b and B_d^0 candidate events are shown in Figure 2. From the unbinned fit to the data, parametrized as a sum of a Gaussian and a linear function, 8 ± 3 Λ_b events and 58 ± 9 B_d^0 events were found. In order to reduce some of the systematic uncertainties, the ratio of product branching fractions was calculated: $\frac{f(b \rightarrow \Lambda_b) \cdot BR(\Lambda_b \rightarrow \Lambda J/\psi)}{f(b \rightarrow B_d) \cdot BR(B_d \rightarrow K_s^0 J/\psi)} = 0.30 \pm 0.13(\text{stat.}) \pm 0.05(\text{syst.})$. The remaining systematic errors are dominated by unknown polarization and decay parameters of the Λ_b , and modelling of the b quark to b baryon fragmentation. By including the measured value of $B(B_d^0 \rightarrow K_s^0 J/\psi) = 3.7 \times 10^{-4}$ and assuming $\frac{f(b \rightarrow \Lambda_b)}{f(b \rightarrow B_d)} \approx \frac{0.1}{0.375}$ the value of $B(\Lambda_b \rightarrow \Lambda J/\psi) = 4.2 \pm 1.8(\text{stat.}) \pm 0.7(\text{syst.}) \times 10^{-4}$ was calculated. As shown in Table 1, this value is consistent with the previous CDF and LEP limits.

5 Measurement of the Λ_b Lifetime

The $pK^-\pi^+$ invariant mass distributions for all $\ell\Lambda_c$ pairs is shown in Figure 3. A clear Λ_c peak is evident for the right sign combinations. No such a peak is observed in the wrong sign sample. A fit of a Gaussian and a linear function returns 197 ± 25 right sign signal events. The Λ_b^0 and Λ_c^+ decay vertices are reconstructed in the transverse plane. The average beam position determined for each run is used as the location of the primary vertex in an event. The

Λ_c^+ vertex is reconstructed from a fit using the $pK\pi$ candidate tracks. The Λ_b^0 decay vertex is formed by extrapolating the $pK\pi$ momentum vector from its vertex to the intersection with the lepton track. The Λ_b^0 decay length is defined as the distance between the primary vertex and the reconstructed Λ_b^0 vertex, projected onto the $\ell - \Lambda_c$ transverse momentum vector. The momentum of the $\ell - \Lambda_c$ pair is used as an estimate of the Λ_b^0 momentum, since there is an undetected neutrino in the decay. The proper decay length calculated using the momentum of the $\ell - \Lambda_c$ pair was called pseudo-proper decay length. A Monte Carlo simulation was used to correct for the difference between the transverse momenta of the $\ell - \Lambda_c$ pair and the Λ_b^0 , in order to estimate the proper decay length. The correction factor had an average value of 0.87 and an RMS width of 0.11.

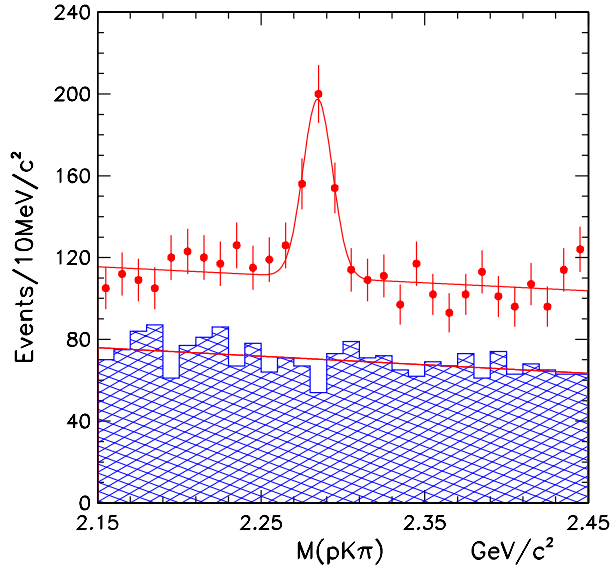


Figure 3: Invariant mass of $pK\pi^- \pi^+$ for the right sign (data points) and wrong sign (shaded histogram) combinations. The results of the fit are imposed on the plot.

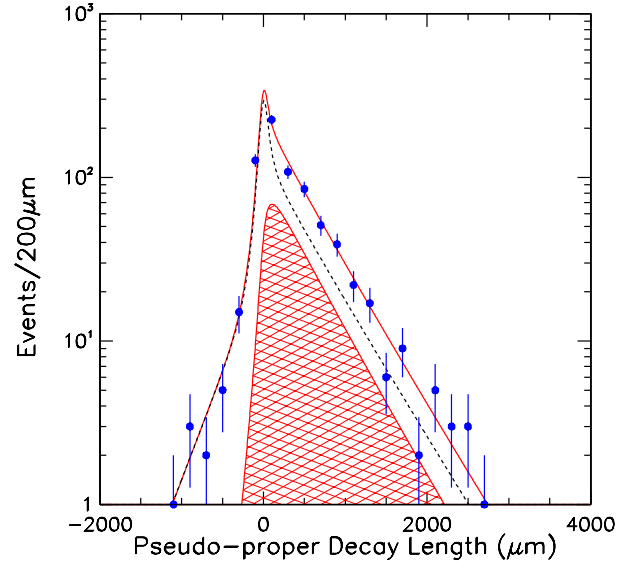


Figure 4: Pseudo-proper decay length distribution for events from the signal region. Solid circles correspond to the data, the solid line is the fit result, the shaded area is the signal distribution, and the dashed line describes the background contribution.

In order to extract the Λ_b^0 lifetime from the measured decay lengths, an unbinned likelihood fit is performed using a likelihood function that accounts for both signal and background components in the sample. The signal function is parametrized as an exponential lifetime function convoluted with a Gaussian resolution function and the momentum correction factor distribution. The background function is described by a sum of a Gaussian resolution function, positive and negative exponential functions to describe the tails, and a positive exponential function to describe the presence of heavy flavor decays in the background sample. Similarly, the background function is convoluted with a Gaussian resolution and the correction factor distributions. Fitting the decay length of these candidate events gives a lifetime value of $\tau(\Lambda_b^0) = 1.32 \pm 0.15$ ps. The pseudo-proper decay length distributions are shown in Figure 4 for the events in the signal region, superimposed with the fit results. The systematic uncertainties

originate from the background definition and parameterization, event selection cuts, estimation of the correction factor, and polarization of the Λ_b^0 . The total systematic uncertainty from the above sources is ± 0.07 ps. As a check of this procedure the Λ_c^+ lifetime was determined from its decay length distribution to be $0.22 \pm 0.03(\text{stat})$ ps, in good agreement with the world average value of 0.20 ± 0.01 ps [14].

6 Measurement of the $f(b \rightarrow \Lambda_b) \cdot B(\Lambda_b \rightarrow e^- \Lambda_c^+ \bar{\nu}_e X) \cdot B(\Lambda_c \rightarrow p K^- \pi^+)$

In the determination of the product branching fraction, a data sample of 20 pb^{-1} of inclusive electrons was used. The selection criteria were similar to those used for the lifetime measurement. Λ_c decay track candidates were required to have transverse momentum greater than $400 \text{ MeV}/c$, for reliable track reconstruction efficiency. The product of the b quark cross section and branching fraction was calculated to be $\sigma_b(p_t^b > 10.5 \text{ GeV}/c) \cdot f(b \rightarrow \Lambda_b) \cdot B(\Lambda_b \rightarrow e^- \Lambda_c^+ \bar{\nu}_e X) \cdot B(\Lambda_c \rightarrow p K^- \pi^+) = 1.9 \pm 0.5(\text{stat.})_{-0.7}^{+0.8}(\text{syst.})$. Using the CDF measurement of the b quark cross section [15] $\sigma_b(p_t^b > 10.5 \text{ GeV}/c) = 2.0 \pm 0.3 \pm 0.4 \text{ } \mu\text{b}$, the product branching fraction was calculated to be equal to $f(b \rightarrow \Lambda_b) \cdot B(\Lambda_b \rightarrow e^- \Lambda_c^+ \bar{\nu}_e X) \cdot B(\Lambda_c \rightarrow p K^- \pi^+) = 9.3 \pm 2.5_{-4.0}^{+4.6} \times 10^{-4}$. This measurement is consistent with other results summarized in Table 1.

7 Conclusions

A search for exclusive decays of the Λ_b baryon was performed using 110 pb^{-1} sample of data collected by CDF over the duration of Run I at the Tevatron Collider. In the decay channel $\Lambda_b \rightarrow \Lambda J/\psi$, 38 candidate events were found in the signal region, including the estimated background of 18.7 ± 1.7 events in this region. Using this sample of events, the Λ_b mass of $M_{\Lambda_b} = 5.623 \pm 0.005(\text{stat}) \pm 0.004(\text{stat}) \text{ GeV}/c^2$ and the product branching fraction $f(b \rightarrow \Lambda_b) \cdot BR(\Lambda_b \rightarrow \Lambda J/\psi) = 0.0042 \pm 0.0018 \pm 0.0007\%$ were measured. From a sample of partially reconstructed decays $\Lambda_b \rightarrow \ell^- \Lambda_c^+ \bar{\nu}$, measurements of the Λ_b lifetime of $1.32 \pm 0.08 \pm 0.05$ ps and lifetime ratio, $\tau_{\Lambda_b}/\tau_{B_d^0}$, of $0.85 \pm 0.10 \pm 0.05$ were obtained. Using 20 pb^{-1} of inclusive electron data, a product branching fraction $f(b \rightarrow \Lambda_b) \cdot BR(\Lambda_b \rightarrow \ell^- \Lambda_c^+ \bar{\nu}) \cdot B(\Lambda_c \rightarrow p K^- \pi^+) = 9.3 \pm 2.5_{-4.0}^{+4.6} \times 10^{-4}$ was measured and was found to be consistent with other measurements.

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